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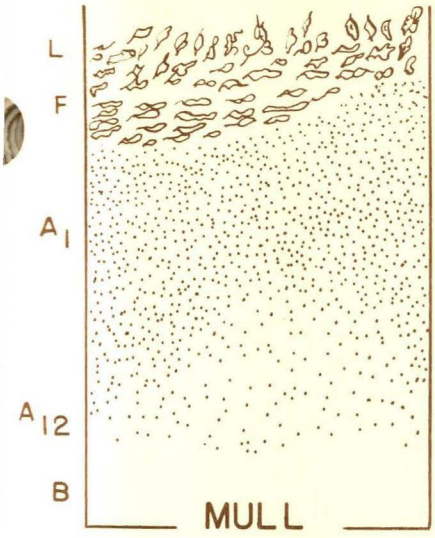

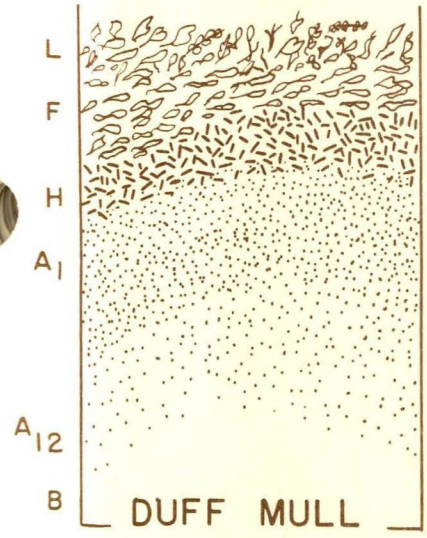

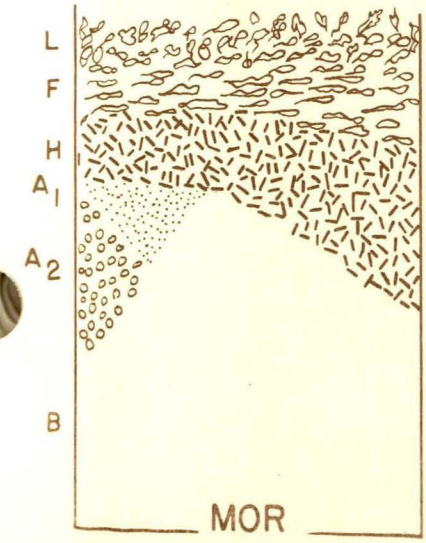

The role of FOREST HUMUS in watershed management in New England

G. R. Trimble, Jr.
Howard W. Lull

PREFACE

This paper is a part of a problem analysis for watershed-management research to be conducted by the Northeastern Forest Experiment Station at the Hubbard Brook Experimental Forest in the White Mountains of New Hampshire.

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The role of FOREST HUMUS in watershed management in New England

by George R. Trimble Jr. *and* Howard W. Lull[1]

Northeastern Forest Experiment Station
Forest Service, U.S. Dept. Agriculture

INTRODUCTION

FOREST HUMUS is one of the most interesting components of the forest environment. Its surface serves as a depository for leaf fall and needle fall, with successive depths marking stages of transmutation from the freshly fallen to the decomposed. And humus is responsive: humus type and depth are indicators of forest treatment and, to some extent, of site quality. Intrigued by these characteristics, foresters and soils men have examined them in detail and have published a wealth of scientific papers on the physical properties of humus, its classification, development, and nutrient content. Most of these papers were about basic studies; little practical application is involved. To date, forest managers have made little use of what is known about humus.

In watershed management, an understanding of the hydrology of humus may offer more immediate practical application. First of all, humus serves a dual function: it stores and transmits moisture; and it helps shield the soil against the soil-eroding force of rainfall. These functions

[1]Mr. Trimble is research forester in charge of watershed-management studies at the Experiment Station's research center at Laconia, N.H. Mr. Lull is chief of the Station's Division of Watershed Management Research.

are well recognized and very nearly axiomatic. Like other facets of watershed management, however, quantitative interpretation lags behind qualitative recognition.

The primary objective of this paper is to bring together existent data that will serve to clarify the function and importance of forest humus to watershed management in New England. Since two-thirds of New England is forest land, this region's water problems and their solution are closely tied up with the use made of this land. In view of this, if forest-humus conditions have important functions in watershed management, then it is important to know what they are; it is important to study the factors that affect humus: and it is important to know if these factors can be manipulated by forest managers; and, if so, how.

A secondary objective is to note where information is lacking. Throughout this paper, attention will be centered on the hydrological properties of forest humus and changes in these properties associated with the response of humus to forest site and treatment.

HUMUS DEVELOPMENT

The term "humus" as used by foresters and as used in this paper refers to the upper soil layers whose characteristics most reflect the effect of organic matter; it includes both organic material and, when present, intermixed mineral matter. The hydrological characteristics of the humus-dominated layers or horizons are governed by the physical properties of the organic matter, their principal constituent.

The organic constituent of the humus layers consists of the more or less decomposed residues of the forest flora and fauna. It is composed of plant parts, the leaves, twigs, limbs, bark, fruit, flowers, stem, roots--all of the parts that drop to the forest floor or that die and rot within the soil. Added to this are the remains of soil flora and fauna and forest wildlife. From this potpourri, humus decays into an organic end-product that is unrecognizable as to source and has considerable uniformity.

Varying in its source, this organic material also varies in its degree of decomposition, ranging from material only partially decayed and possessing many of its original features to totally decayed materials. This transformation involves numerous recurrent cycles. At its earliest, humus formation can conceivably begin when a leaf falls on bare soil and decay begins. Before the leaf is totally decom-

posed, a second-year leaf falls, initiating a second cycle of decomposition. Before the first cycle is completed, several cycles of decay may be in process. Not all of the plant and animal debris decay at the same rate, so the cycle becomes complex--wheels within wheels, so to speak. Nikiforoff describes the cycles and end-product as follows (24)[2]:

> Hence, each year the beginning of a new cycle superimposes itself upon the more advanced stages of all preceding cycles that have not yet reached final stages. Consequently, the soil organic matter in any year consists of various materials which represent all stages of the long cycle from the initial to the last. Because of this, the general composition of the soil organic matter does not change from year to year, and such a steady state conceals the cyclicity of its formation.

Humus accumulates when annual additions are greater than annual decay. The gradual development of a humus layer provides the habitat to encourage decay--the seeds for its own destruction--so that gradually the annual rate of decay equals the rate of deposition of new materials. As Nikiforoff puts it (23):

> From that time the two processes--formation and mineralization--proceed at an equal rate, and the soil may be said to have reached a state of maturity or one of equilibrium with its natural environment. The average content of humus in the mature soil remains relatively constant as long as no change in natural condition occurs. Any change in the natural condition that upsets the equilibrium will be followed by a corresponding change in the humus content of the soil.

Changes in natural conditions are frequent as forest stands become the prey of fires or diseases or are subject to various degrees of cutting; so it follows that only in rare instances will humus depth be in equilibrium with its environment. More often than not, humus depth is less than normal; for processes leading to reduction of humus are much more rapid than those directed toward its restoration.

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[2]Underlined numbers in parentheses refer to Literature Cited, page 31.

HUMUS CLASSIFICATION

The system of classifying forest humus generally used in the United States (7) is based on the arrangement and nature of the humus layers (see Appendix). These are defined as follows:

F - Fermentation layer. Partially decomposed litter. Origin of material still recognizable.

H - Well-decomposed, dark, amorphous organic matter, unrecognizable as to origin. Lower boundary abrupt.

A_1 - Top layer of mineral soil. Intimate mixture of organic and mineral fractions. Lower boundary diffuse. In the mor type this horizon is absent or is present only as a very weakly developed layer with slight admixture or organic matter.

Based on the degree of incorporation of organic material into the soil, forest humus has generally been broadly classified as either MOR or MULL. The term MOR is used to describe the condition where the H layer rests on the surface soil with practically no mixing. In contrast, a MULL type has no H layer, and the organic material is well mixed with the upper portion of the mineral soil. In the most recent classification there appeared an intermediate type, a DUFF MULL; this combines features of both mors and mulls.

Each of these three types has two to six subtypes based on identifiable differences in organic-matter content, structure, and thickness (7). This classification, based strictly on morphological features, has been criticized by Wilde (35) in that it is not correlated with forestry practice or physical relationships. Wilde suggests a classification based on "...an analysis of the underlying causes of humus formation and establishment of the major genetic types of humus development..."

Certain factors have been observed that tend to be associated with the development of mors over mulls in the Northeast. These are:

Podsols versus brown podzolic soils.

Coniferous cover versus hardwood cover.

A low versus a high soil pH.

These relationships have been noted and discussed in general

(not specifically for the Northeast) by numerous observers, among whom were Lutz and Chandler (20) and Romell and Heiberg (26). However, the real cause-and-effect relationships among these factors and the humus type have never been satisfactorily established.

In this connection, W. R. C. Handley has recently reported results from an exhaustive investigation on the reasons for the differential formation of mull and mor (5). He concluded that stabilized leaf proteins are an important factor in the processes of mor formation. These proteins, stabilized in the dying leaf by tannin-like materials, are so resistant to decomposition that the tissues in which they occur accumulate on the surface of the mineral soil. Withholding of supplies of available nitrogen in these proteins may also delay decomposition of other material. Proteins found in mull-producing litter, on the other hand, are not so resistant to decomposition, probably because of differences in molecular composition and structure. Their ready decomposition is likely due to adequate supplies of more readily available nitrogen.

In collating literature on the physical properties and moisture relationships of forest humus, one finds a certain amount of ambiguity as to whether or not freshly fallen litter is an integral component. The accepted classification system, described above, does not consider this material because of its transitory nature. Blow has reported, for example, that in an upland oak stand in Tennessee 4 percent of the leaves fell by late August, an additional 42 percent by mid-October, and the balance of 54 percent by early December. Total weight of the forest floor increased by December to 5.5 tons per acre. By the following August it decreased by decomposition to 4.2 tons (2). Annual deposition of longleaf pine litter, on the other hand, has shown two maxima, 19 percent of annual fall in October and 40 percent in May, June, and July (12).

Because of its evanescence, many investigators have not included litter in their measurement of total accumulation of organic matter. Exclusion or inclusion of litter will also affect water-storage measurements or estimates even though the storage capacity of litter is much less than that of underlying more decomposed materials. Generally, plot measurements of infiltration or surface runoff are made with litter intact. Conifer litter may affect storage and infiltration measurements more than hardwood because most studies of this kind are made during the growing season when hardwood litter is at a minimum.

In the majority of the western and southern studies

cited in this paper, hydrologic functions of the total accumulated organic layer have been studied. In studies of humus in the Northeast, except for infiltration studies, the litter effect has generally been excluded. There are good reasons for the differences in approach among the West, and South, and the Northeast. First, southern and western studies have been more generally concerned with conifers and northeastern studies with hardwoods; and the amount of conifer litter depends much less on annual leaf fall than hardwood litter does. Second, the importance of litter in respect to the greater humus depth in the Northeast is relatively much less than in the South and West, where litter may form the bulk of the total organic accumulation.

Throughout this paper an attempt will be made to use designations that will indicate whether the data under discussion includes or excludes litter. All tabular material will be designated clearly either as forest floor, which includes litter, or as humus exclusive of litter, or by F and H humus designations. The term "litter" will be used only to designate current annual accumulations.

PHYSICAL PROPERTIES

The watershed functions of forest humus pertain to its effect on infiltration and percolation (or the movement of water into and through the soil), on water storage, and on evaporation. The manner of performance of these three functions is dependent on physical properties of humus which are related, namely, its light weight, porosity, and great water-holding capacity.

Its light weight is illustrated in the tabulation of bulk densities determined by various investigators (table 1).[3] Densities range from 0.07 to 1.09. The average density for the H layer is twice that of the F layer: 0.22 compared to 0.11. Bulk densities are less for mor humus than for mull humus (which contains mineral soil); and they vary also within the mulls with firm mull having a higher bulk density than the other mulls.

According to Lutz and Chandler (20) the bulk density of the A_0 horizon of forest soils (the FH layer) is about 0.2; the A horizon is commonly less than 1.0; and values of 1.5 or more are characteristic of deeper horizons. As given

[3]Bulk density is the ratio between the oven-dry weight of a given volume of soil and the weight of an equal volume of water.

in table 1, the weight per unit volume of mor humus is about one-fourth that of mull humus and would be about one-seventh that of deeper mineral horizons of about 1.5 bulk density.

Associated with the comparatively low density is high porosity. The bulk density of 0.22 for the H layer of mor humus, with an estimated specific gravity of 1.5, gives a total porosity of 85 percent of the volume; the average bulk density of 0.11 for the F layer gives a total porosity of 93 percent. In contrast, a mineral soil with bulk density of 1.5 and a specific gravity of 2.65 will have a total porosity of 43 percent--about one half that of mor humus. Mull humus has porosity values that lie between those of mor humus and mineral soil. Within the mull types, firm mull is the least porous.

Table 1.--Bulk densities of humus

Humus designation	Location of study	Humus layer			Literature reference
		F	H	A_1	
Greasy mor	New Hampshire	0.09	0.18	--	(19)
Mor	Connecticut	.07	.18	--	(19)
Mull	Connecticut	.07	--	--	(19)
Firm mull	Mass., N. H.	.18	--	1.09	(*)
Firm mull	Pa., New York	--	--	.87	(33)
Coarse mull	Mass., N. H.	.13	--	.94	(*)
Coarse, fine, and medium mull	Pa., New York	--	--	.51	(33)
Firm mull	Mass., N. H.	.13	--	.87	(*)
Granular mor	Mass., N. H.	.11	.27	--	(*)
Fibrous mor	Mass., N. H.	.09	.22	--	(*)
Greasy mor	Mass., N. H.	.15	.22	--	(*)
Mor	Pa., New York	--	.31	--	(33)
Fibrous duff	New York	--	.14	--	(25)
Greasy duff	New York (upper H)	--	.18	--	(25)
Greasy duff	New York (lower H)	--	.24	--	(25)

*Morey, H. F. The relationship of humus to the vegetation-soil complex and its application to the flood control problem. Allegheny Forest Expt. Sta. (now Northeast. Forest Expt. Sta.). 35 pp., unpublished. 1941.

Along with high porosity and light weight per unit volume, humus possesses a great water-holding capacity. Its field capacity (the amount of moisture it will retain against the pull of gravity) ranges between 100 and 200 percent of its oven-dry weight. Lowdermilk reports 180 percent for forest floors of pine-fir and pine-fir-cedar stands in California (15). In a recent study, Blow found 135 percent capacity for upland oak forest humus in Tennessee (2). Under California chaparral, Kittredge found forest-floor

values ranging from 115 to 205 percent (13). In another study, Kittredge reported comparable values of 150, 182, and 186 percents for Douglas-fir, Canary pine, and Monterey pine respectively; forest floors of white fir on the west slope of the Sierra had field capacities of 161 to 183 percent (14).

These are average values for forest floors that include the litter and humus layers. Litter is known to have a lesser water-holding capacity than the humus layers (12); quantitative data on this point and on the relationship of water-holding capacity to stage of decomposition appear to be few.

Minimum field-moisture contents range from 20 to 40 percent by weight. Blow found a value of 20 percent in his Tennessee study (2). Hale and Trimble reported permanent wilting percentages of 37.5 for mor and 19.3 for mull as determined from samples taken during a drought in the Upper Susquehanna river watershed; the soils were gravelly silt loams (4). According to Kittredge, a dry forest floor under field conditions rarely contains less than 10 to 15 percent moisture (12).

INFILTRATION & PERCOLATION

The forest floor facilitates the entrance of water into the soil body in several ways. Being highly porous, it offers little resistance to the downward movement of water toward the mineral soil, yet it protects the mineral soil against rainfall impact. This protective property extends to the shelter and food it provides the soil fauna whose burrowing serves to increase soil porosity and infiltration. Aggregation, through interaction of soil particles with organic matter, also increases porosity. Finally, the forest floor forms an obstruction to surface runoff, increasing the frictional resistance to overland flow, thereby increasing the depth of surface detention storage and permitting infiltration to take place for a longer period.

These qualitative relationships are well recognized. Quantitatively, the influence of a forest floor on infiltration has been given some study by measuring infiltration or surface runoff on plots with and without litter and/or humus. The classic example is Lowdermilk's early study in California (15), where he found that surface runoff from plots on which the forest floor had been burned off was 3, 9, and 16.5 times greater than runoff from unburned plots for fine sandy loam, sandy clay loam, and clay loam soils respectively: the forest floor was most effective on the

finest-textured soil.

In Connecticut, Lunt found that about twice as much rainfall percolated through 4-inch deep lysimeters with litter-covered soil as through lysimeters with bare soil (18).

Two infiltrometer studies provide additional evidence. In the upland oak type of the Ozarks, Arend found an average infiltration rate of 2.12 inches per hour for unburned plots compared to 1.32 inches per hour for plots that had been burned over annually for 5 or 6 years. This was an average reduction of 38 percent; reductions for the various soil types ranged from 20 to 62 percent. Comparative rates for undisturbed and raked plots were 2.36 and 1.94 inches respectively, a reduction of 18 percent (1). Johnson, in Colorado, found that removing the forest floor reduced infiltration capacity from 1.52 to 0.92 inches, a reduction of about 40 percent (11).

In a 3-year record of surface runoff from lysimeters installed under Ponderosa pine in California, Rowe found an average surface runoff of 0.33 inch (from 36.80 inches of annual rainfall) as compared to 13.30 inches from a lysimeter kept bare (27).

All of these studies indicate that high infiltration rates are associated with a normal forest floor. Once it is removed by burning or raking, infiltration rates are sharply reduced and surface runoff is increased several-fold. This effect is greater for fine-textured soils than for coarse, and greater on burned plots than on raked plots. These results are applicable to areas where intense ground fires destroy the forest floor, and to the occasional instances where litter is removed for mulch or barn straw.

Since the beneficial effects of organic matter in increasing infiltration rates and in reducing surface runoff have been proved, the question then can be narrowed down from Does the forest floor affect infiltration? to What differences in infiltration result from differences in humus type and/or depth?

As to the effect of humus type: there have been no large-scale studies designed specifically to determine whether mors or mulls or their variants, with comparable depths, have different infiltration rates. Occasionally one will come upon a reference that a shingle effect of recently fallen hardwood leaves tends to increase runoff. Again, qualitative data are lacking.

There is, however, some evidence that forest-floor depth affects infiltration. In California, Rowe found surface runoff of 5.9, 2.2, 0.5, 0.3, and 0.5 inches for bare soil, and 1/4-, 1/2-, 3/4-, and 1¼-inch depths of forest floor, respectively. In this instance, increasing depths beyond 1/2 inch had little or no effect (27).

Table 2.--Infiltration indices for 2 inches of storm rainfall

Forest condition	Average humus depth[1]	Deep well-drained soils[2]	Shallow well-drained soils[3]	Imperfectly drained soils[4]	Poorly drained soils[5]
	Inches	Inches per hr.	Inches per hr.	Inches per hr.	Inches per hr.
Sawtimber and poletimber, poorly stocked; seedling and sapling	1.0	1.04	0.41	0.49	0.28
Sawtimber and poletimber, fair stocked	1.7	1.43	.56	.67	.38
Poletimber, well stocked	2.3	1.71	.67	.79	.46
Sawtimber, well stocked	3.3	1.98	.77	.92	.53

[1]Excludes litter.

[2]More than 24 inches deep.

[3]Less than 24 inches deep.

[4]Restriction layer between 18 and 24 inches.

[5]Restriction layer between 8 and 18 inches.

Tripp and Whelan have also given data that show the influence of humus depth on infiltration.[4] Infiltration indexes are given in table 2 for four soil storage-drainage conditions of forest land in the Kennebec River basin in Maine. The infiltration index is defined as that average rate that, when applied to an actual storm rainfall pattern, will yield mathematically a volume of surface-runoff that is equivalent to that observed.

Within each of the four soil conditions, such factors as antecedent moisture and soil compaction from logging will also affect the infiltration index. It is noteworthy that the index for conditions of highest infiltration is about twice that of the poorest condition in each soil category.

[4]Tripp, Norman R., and Whelan, Donald E. Evaluation of flood-control effects of the agricultural program for the Kennebec River basin. Northeast. Forest Expt. Sta. 45 pp., illus. 1953.

Lowest indices for forest land were almost identical to those determined for good pasture and hayland. The increase of infiltration with depth of humus in this study, contrary to the California findings, is due to the differences in research methods. California findings were based on plot-lysimeter studies in which, with successive increases of forest floor depth, the singular effect on infiltration soon reached a point of limiting return. The study by Tripp and Whelan was based on theoretical routing of water through the soil profile, using soil-core percolation rates and moisture-storage values for individual soil horizons in the different soil-cover complexes.

So far, only summer infiltration has been considered. The relationship of a forest floor to infiltration under winter freezing conditions is influenced by its effect on frost type and depth. Though this phase of infiltration has been discussed more that it has been studied, a few observations of frost conditions in open and forested land have shown that frost associated with forest humus is often more permeable than the frost type found in unprotected open areas. It has also been shown that humus-protected soil does not freeze so deeply nor so extensively as open-land soil. Quantitative data as to humus type and depth in relation to frost type and depth and frost-infiltration relationships are lacking.

In addition to its influence on infiltration (the movement of water into the soil), a forest floor also affects percolation--the movement of water through the soil. Trimble, Hale, and Potter (33) compared percolation rates through humus layers and through the surface soil of cropland and pasture. Working with soil cores, they found percolation rates of 236 and 132 inches per hour for mors and mulls in the Allegheny watershed in New York and Pennsylvania. Rates for row crops and pasture-hayland conditions were 3 to 7 and 8 to 22 inches respectively. Firm mull under grazed forest stands had a rate of 30 inches per hour. Percolation rates for fine, coarse, and medium mulls did not differ significantly from each other; ungrazed firm mull had a significantly lower rate, about one-half that of the other mulls. Subtypes of mor humus gave percolation rates that showed no significant differences (33).

The effect of a forest floor on percolation in the underlying soil is more difficult to isolate. Lunt observed that aggregation was greater under red pine litter in the 1- to 3-inch depth than under bare soil (17), which suggests that percolation was facilitated immediately below the litter.

From the above, it is evident that percolation rates through humus are high and--even for the most slowly drained type-firm mull--are not a limiting factor in soil-water drainage. The effect on percolation rates immediately below the humus layer is not known, though it is reasonable to assume that, because organic matter facilitates aggregation and aggregation facilitates percolation, an effect exists.

SUGGESTED RESEARCH

Recognizing the high summer infiltration rates that are associated with normal accumulations of different types of humus under undisturbed forests, we can conclude that under these conditions humus layers do not limit the movement of water into the soil. The same conclusion can be reached for percolation rates. Three areas of research remain:

1. Depth and type.--The relationship of forest-floor depth and humus type to infiltration should be investigated. It would seem particularly pertinent to determine for each major humus type the minimum depth of forest floor that is sufficient to control surface runoff and erosion.

2. Winter infiltration.--This represents probably the largest gap in our knowledge. During winter freezing, another factor that affects infiltration is introduced: soil frost. A humus depth that is just sufficient to protect the soil in the summer against rainfall impact may not be sufficient to prevent the formation of impermeable frost in the winter. A study of multiple relationships is necessary to determine the relationship of humus type and depth to frost type and depth, and to determine the influence of frost type and depth on infiltration and percolation.

3. Aggregation and percolation.--The influence of humus on aggregation of the underlying soil and its effect on percolation deserves study. Particularly interesting would be determinations of the time required for aggregation to occur after humus accumulation, the depth of aggregation, and the differences in aggregate formation that are associated with mull and mor types.

In such studies, infiltration could be measured on small plots either with rings or infiltrometers or by measuring natural runoff. Percolation could be measured on soil cores in the laboratory, or with rings in the field by removing humus to the desired depth and setting the ring directly into the material tested. With these methods, only

relative results would be obtained. For the time being, that is all that can be expected: with so little knowledge in these fields of study, determination of even relative effects would be a major contribution.

WATER STORAGE

The addition of organic materials to the soil and the development of humus increases the water-storage capacity of the soil. If this is not the most important function of humus in watershed management, it is certainly the most complex. The infiltration and percolation relationships of forest humus and (as will be discussed) its effect on evaporation are largely satisfied by having minimum humus depths to prevent rainfall splash and shade the soil surface. The storage function is more complex in that it varies more specifically with type of humus and humus depth.

For forest-watershed management, the increase in water-storage capacity by humus development has several effects. Its most important pertains to flood control: increased retention storage provides greater opportunity for storage of flood-producing rainfalls; and increased detention storage slows the movement of the rainfall to stream channels. The importance of these effects is in proportion to the relative increase in storage; this, in turn, is in proportion to the total storage capacity of the soil, a function of its texture and available depth. Shallow-soil areas are benefited proportionately the most. Increasing storage capacity of shallow soils may also serve to provide greater moisture supplies for growth, though the contrary possibility has been suggested: that accumulation of surface organic matter, by reducing the amount of precipitation that reaches the underlying soil, may initiate woodland degeneration (29).

Factors that affect humus type and depth directly affect water storage and will be discussed from that point of view. Before considering these factors, attention will be paid to water-storage capacities of humus.

STORAGE CAPACITIES

Since organic material added to the soil increases its capacity to store moisture, the increase will depend on the total amount of organic material added and its water-retention and -detention capacities. For the objectives of this paper these have been estimated from data on weight of organic material and humus depth.

On the weight basis, total amounts of organic material added to the soil have been shown by Lunt (16) to vary from about 11 to 131 tons per acre in New England (table 3). Estimated water storage capacities for these accumulations ranged from 1.74 to 0.14 inches, based on an estimated retention or field capacity for the humus of 150 percent by weight. The average value for the four hardwood stands in

Table 3.--Weight of accumulated organic material and estimated water-retention capacity

Forest stand	F layer	H layer	Total	Estimated water retention capacity
	Pounds per acre	Pounds per acre	Pounds per acre	Inches
New Hampshire				
White pine 100 years old	42,981	75,697	118,678	0.79
White pine 100 years old	21,107	46,531	67,638	.45
Spruce--hardwoods--birch-maple with spruce understory	--	263,547	263,547	1.74
Spruce-hardwood	15,350	95,460	110,810	.73
Connecticut				
Hardwood--oak, beech, birch	10,361	45,860	56,221	.37
Hardwood--oaks	--	88,553	88,553	.59
Hardwood--oak, maple, ash	12,760	80,781	93,541	.62
Hardwood--oak	11,800	53,726	65,526	.43
Red pine 30 years old	42,981	--	42,981	.28
Red pine 27 years old	--	--	27,920	.18
White pine 27 years old	--	--	21,590	.14

Table 4.--Humus depth and moisture-storage capacity of mature stands in the Connecticut River watershed

Forest type	Humus type	Depth	Storage capacity	
			Available retention	Detention
		Inches	Inches	Inches
Medium-textured soils (loams)				
Temporary hardwoods (northern New England)[1]	Mull	3.5	0.91	0.98
Long-lived hardwoods (northern New England)[2]	Mull & mor	7.3	2.19	2.19
Hemlock-spruce-fir (northern New England)	Mor	7.6	2.51	2.43
Coarse-textured soils (sands, sandy loams)				
Temporary hardwoods (southern New England)[1]	Mull	2.6	--	--
Long-lived hardwoods (southern New England)	Mull & mor	3.5	--	--
Hemlock-spruce-fir (northern New England)	Mor	6.0	--	--

[1]Temporary hardwoods: Aspen, pin cherry, gray birch, and paper birch.

[2]Long-lived hardwoods: Northern hardwood type in northern New England, but in southern New England includes the oaks.

Connecticut was 0.50 inch and for the three pine stands 0.20 inch, about one-half to one-fourth the mean capacity of the four New Hampshire sites.

On the depth basis, average maximum humus depths under mature forest stands (estimated in the course of flood-control surveys conducted by the Department of Agriculture in the Connecticut River watershed) are given in table 4 for medium- and coarse-textured soils. By these data, maximum depths are about 7.5 inches for medium-textured soils for both mull and mor humus types under both long-lived hardwood and spruce-fir-hemlock stands. These figures are based on data from New Hampshire, Vermont, and the Berkshire section of Massachusetts. They represent conditions in old undisturbed stands and are maximum values from curves of humus depth accumulation over age, such as shown in figure 1.

To estimate soil-moisture storage capacities for these humus depths, appropriate soil-moisture constants were

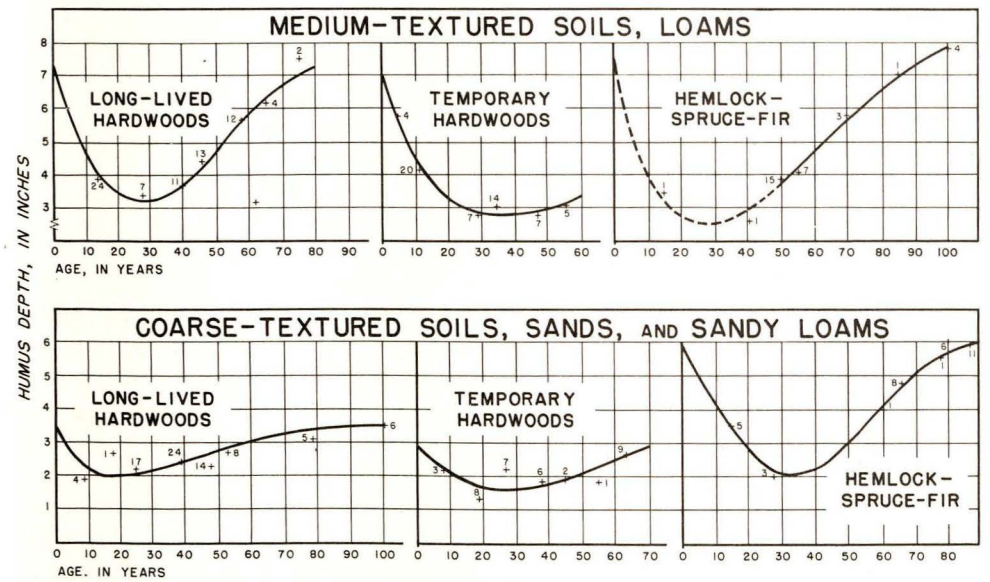

FIGURE 1.--Humus depth - age relationships. The numbered points indicate number of plots.

derived, based largely on physical properties of humus as already noted. Per-inch depth values for three humus types on medium-textured soils are given in table 5; the values for the mor and coarse mull were used to derive the retention and detention capacities given in table 4. For each of

the three forest types listed in this table the maximum amount of water held in the humus is about equally divided between available retention and detention storage. Storage capacity is least for the temporary hardwoods (about 0.95 inches in each type of storage) and greatest for the hemlock-spruce-fir types (about 2.50 inches capacity in each storage category). Moisture-storage constants were not available to determine storage capacities for mull humus layers of the coarse-textured soils.

Table 5.--Moisture-storage capacities per inch of forest humus on medium-textured soils in the Northeast

Humus type	Bulk density	Specific gravity[1]	Total pore space	Retention storage[2]	Wilting percentage (4)	Available storage	Detention total[3]	Detention storage corrected[4]
			Percent	Percent	Percent	Inches	Percent	Inches
Mor	0.22	1.52	85	40.0	7.4	0.33	45	0.32
Coarse mull	.51	2.38	79	40.0	13.8	.26	39	.28
Firm mull	.87	2.56	66	40.0	10.9	.29	26	.19

[1]Calculated using 1.5 as a specific gravity of organic matter and 2.65 as specific gravity of mineral soil. Mor was estimated to contain 95 percent organic matter, coarse mull 15 percent, and firm mull 5 percent.

[2]On a volume basis, retention storage appears to be in the neighborhood of 40 percent (33) which is about equivalent to previous estimates of 150 percent by weight and 0.22 for bulk density.

[3]Detention pore space was determined by subtracting retention storage (40 percent) from total pore space. Total pore space was calculated using bulk densities and specific gravities.

[4]Since total detention storage is never fully utilized in moisture storage, these volumes were multiplied by a correction factor (0.72) as determined by Trimble, Hale, and Potter on core samples (33).

Any comparison of water-storage capacities in mull versus mor humus layers should be made with consideration of the nature of those two types. An accumulation of mor humus is almost entirely an addition to the depth of mineral soil and thus an addition to the profile storage capacity. But a mull humus of the same depth represents a mixing with the mineral soil of a much lesser amount of organic matter--and therefore an addition of considerably less profile storage capacity. This relationship has been reported by Trimble (32).

To summarize, water-holding capacities vary with humus type and, in the case of mulls, with texture of the mineral soil. About 40 percent of the mor humus H layer may be considered retention storage, 15 percent solids, and 34 percent detention storage. Thus a 4-inch depth of mor can retain about 1.60 inches of water (including that below the wilting percentage) and detain about 1.28 inches. As shown in table 5, total storage capacities of an equal depth of mull humus are apt to be somewhat less.

FACTORS THAT AFFECT HUMUS DEPTH & TYPE

Other than the flood-control survey data just cited, only a few data on depth of humus accumulation are available. Lunt measured humus depths under a number of forest stands in Connecticut and New Hampshire. He found that the F and H layers in Connecticut accumulated to a depth of about 2 inches. Under hardwoods, the F layer averaged about 0.4 inch and the H layer 0.8 inch. Under hemlock, 3- to 4-inch layers were occasionally found. In New Hampshire, Lunt reported humus depths of 2 and 3-1/4 inches under white pine and 3-1/4 and 5-3/4 inches under spruce-hardwoods (16). In oak stands in the mountains of West Virginia, Trimble and Weitzman found humus depths of 1.8 to 4.0 inches, varying with site index (34). It is doubtful that any of these measurements represent maximum accumulations under undisturbed conditions.

Storage functions of forest humus are related directly to the type and amount of humus, which, in turn, are related to a variety of environmental and induced factors. Among the influencing environmental factors are soil texture, soil drainage, climate, topography, species composition, and age; humus depth is also correlated with site quality through joint relationships with soil and topographic factors. Induced factors include disturbance from cutting, grazing, and fire. These factors have been discussed in some detail by Kittredge (12) and by Sartz and Huttinger (30) as they affect humus accumulation. Here, emphasis will be placed on water storage, noting in passing some deficiencies in information. The following discussions are related to humus layers on well and moderately drained soils. On poorly drained soils, humus conditions are governed largely by the degree of waterlogging.[5]

Climate

The climatic effect on humus depth and storage can be visualized from a statement in Jenny's text on soil formation (8):

> If we consider the characteristic (virgin) forest soils from the subarctic regions of eastern Canada to the Appalachian regions of Kentucky and Tennessee, it

[5] Northeastern Forest Soils Group. Report of the Committee on Classification of Forest Humus on Poorly Drained Soils. 6 pp., unpublished.

will be noticed that the most conspicuous differences lie in the depth and condition of the sum total of organic material that remains above the mineral soil In the northern extremes, these layers are excessively deep and slow to decompose. In the southern example, they are shallow and subject to rapid decomposition.

To illustrate this, Kittredge has compiled a range of forest-floor weights increasing with decreasing latitude from 1.7 metric tons per acre for an old-growth longleaf pine stand in Florida to 119.2 tons for a birch, sugar maple, and spruce stand in New Hampshire (12). Recent measurements by Metz of the total weight of the forest floor in South Carolina hardwood stands (21) permit a comparison with Lunt's measurements in hardwood stands in Connecticut (16). Oven-dry weights of organic matter in South Carolina under yellow-poplar, hickory, and oak stands were 11,940, 8,000, and 13,030 pounds per acre respectively, averaging about one-seventh of the average weight of 75,960 pounds for four measurements reported by Lunt (table 3).

As Jenny et al have shown (9), decomposition rates of organic matter are dependent on both temperature and rainfall. Temperature is probably the most influential climatic factor that affects decomposition in the Northeast, varying relatively more with latitude than with rainfall. Roughly, the frost season in northern Maine is 60 to 80 days longer than that in southern Pennsylvania. Also, average January and July temperatures are 10 and 15 degrees lower in northern Maine. These differences are noteworthy in light of Spaulding and Hansbrough's statement that slash-decay fungi made little or no growth at temperatures below 40°F. and require temperatures of 70°F. or higher for most rapid decay (31).

From data available, such as those in tables 3 and 4, it appears that the greater humus depths (and therefore greater storage capacity) in the White Mountains in New Hampshire may give humus an important role in watershed management in that region.

While data show that humus layers are deeper in the northern than in the southern part of the United States, this should not be construed as an indication that organic matter is unimportant for watershed purposes in the South. Because of its lesser depth, the forest floor does not have so great a storage capacity as in the North; but its protective functions and its propensity to facilitate infiltration remain.

Topography

Apparently the only information on the effect of topography on humus depth was obtained by Sartz and Huttinger (30). They show that the depth of mull humus in the Allegheny River watershed varied with aspect. Significantly greater accumulations were measured on northeast slopes where the average depth for all stands was 3.33 inches; on level ground, the depth was 2.35 inches. With 40 percent retention, this is a difference of 0.39 inch, a substantial portion of the field capacity involved.

Quantitative information on the influence of slope percent and position on slope is lacking; but observations indicate that humus is deeper in hollows than on ridges and deeper on flat areas and gentle slopes than on steep slopes.

Stand Composition, Age, & Site Quality

The effect of stand composition on humus depth and storage may be easily confounded with climate and topographic effects. Generally, according to Kittredge (12), there are no marked differences in annual deposition of litter by deciduous and conifer species. However, data in table 3 indicate that in the Northeast there may be significant differences in accumulation by forest types. In this connection, data in table 4 indicate that in the Connecticut River watershed the hemlock-spruce-fir stands develop deeper humus layers than the long-lived hardwoods on both loams and sandy loams. The conifer humus types are predominantly mors and the hardwood are predominantly mulls. This comparison, however, is based on meager data; information from designed studies is needed.

The relationship of stand age to humus depth has been studied in the Northeast by measuring and plotting these variables so as to show humus reduction after clear-cutting and the subsequent build-up of humus depth (22). Several examples are given in figure 1. Rates of humus accumulation are given in table 6 for the periods when annual accumulation exceeded decomposition. As noted, it required from 45 to 80 years to reach maximum humus depths starting with initial depths ranging from 1.6 to 3.3 inches.[6] Rates of accumulation are variable, and there is a tendency to higher rates in the more northerly locations. Sartz and Huttinger's

[6]These initial depths are taken at the low point of the humus-depth over age curves; they appear to be reached between the 25th and 35th years of regrowth after clear-cutting.

data showed a reduction in humus depth after maximum values are reached (30). However, this reverse trend was based on very few data.

Humus depths also vary with site quality, as can be noted in the comparison of medium with coarse soils in table 4. Kittredge (12) has reviewed the literature on this relationship and concluded that the better the site, the deeper the humus. For the Northeast, supporting evidence has recently been reported by Trimble and Weitzman (34). They found average humus depths of 1.8 to 4.0 inches in oak stands in West Virginia associated with site indexes of 40 to 90 feet. The humus types were mostly medium and duff mulls. In terms of retention water storage these depths are equivalent to about 0.7 to 1.6 inches.

Also in West Virginia, the senior author has observed that humus can be strongly influenced by soil origin. Under comparable forest stands on similar topography, humus on a fertile limestone soil was about 4 to 6 inches deep but 3 to 4 inches deep on a nearby soil derived from sandstone and shale. Humus types also differed: the humus on limestone was predominately coarse and fine mull; the humus associated with the sandstone and shale was medium mull.

Though a positive relationship between humus depth and site quality appears to be established for mulls, one has not been established so conclusively for mors. For

Table 6.--Rates of humus accumulation

Forest type	Location	Humus depth[1]		Time interval	Rate of accumulation in 10 years	Literature reference
		Beginning	Maximum			
		Inches	Inches	Years	Inches	
Long-lived hardwoods (loams)	Connecticut River watershed	3.3	7.3	45	0.89	(*)
Hemlock-spruce-fir (loams)	" "	2.7	7.6	70	.70	(*)
Temporary hardwoods (sand, sandy loams)	" "	1.6	2.6	35	.29	(*)
Long-lived hardwoods (sand, sandy loams)	" "	2.0	3.5	80	.19	(*)
Hemlock-spruce-fir (sand, sandy loams)	" "	2.0	6.0	60	.67	(*)
Northern hardwoods (loams)	Allegheny River watershed	2.3	3.6	60	.22	(30)
White pine-hemlock	" "	1.6	2.7	80	.14	(30)

*Morey, H. F. The relationship of humus to the vegetation-soil complex and its application to the flood control problem. Allegheny Forest Expt. Sta. (now Northeast. Forest. Expt. Sta.). 35 pp., unpublished. 1941.

[1]The humus depths are composed of FH in mors and FA_1 in mulls. The F layer is generally deeper in mors than in mulls, sometimes being as deep as 1.5 inches in the former while rarely measuring more than 0.5 inch in mulls.

mors, the scanty data available indicate a negative correlation. For example, Young found that increasing depths of mor humus were correlated with decreasing site index of white pine in Maine (36). Extremely thick accumulations of mor humus under spruce stands on poor sites have also been observed by the senior author. While the production of organic matter is no doubt positively correlated with site quality, the factors that affect the decomposition of mor humus have not been so correlated to date.

Induced Factors

The influence of such induced factors as forest cutting, fire, and grazing on humus accumulation will vary obviously with the intensity of the disturbing influence and the situation and condition of the humus, including its location and age. When the forest canopy is reduced by cutting, humus accumulation and depth are affected. Sartz and Huttinger, for instance, show in the study previously cited (30) that humus under good stocking (70 to 100 percent canopy cover) was about 0.5 inch deeper than in fair-stocked stands (40 to 70 percent).

The effect of fire is likewise rather variable, being a function of its intensity and humus type and condition --which also react on intensity.

Obviously both fire and reduced stocking will have a negative effect on humus accumulation, the magnitude of which is probably predictable, given sufficient basic information not now available. For practical application, there may be little reward in determining fire intensity-humus depth relationships because fire may be classed as an unplanned event, the consequence of which must be accepted regardless of its effects. Predicting the effects of cutting may be more important in a practical sense if marked reductions of humus result from partial cuttings. One of the important objectives might be to determine the stocking in various-aged stands at which annual deposition of litter exceeds annual rate of decay.

Like fire, grazing has a deleterious effect on humus accumulation. Trimble et al (33) note that the volume weight of grazed mulls was 0.92 as compared to 0.51 for ungrazed coarse, medium, and fine mulls. This is equivalent to about a 45-percent reduction in total pore space. Retention storage in percent by volume was not affected, but detention storage dropped from 23.4 to 12.6 percent. In a study in western North Carolina Johnson reported that grazing reduced total porosity 49, 13, and 5 percent in the 0 to 4-inch soil depths in cove hardwood, oak-hickory, and pine-oak types

(10). Differences reflect different intensities of grazing.

The effect of induced factors on humus type has perhaps been less clearly defined than the effect of these factors on humus depths. However, as previously mentioned, the type of cover--which is a factor susceptible to modification--has been shown by investigators to be related to the formation of mull and mor humus.

Probably the most obvious effect of a forest land-use practice on humus type is the effect of woodland grazing in producing a firm mull. This condition was widely observed during U. S. Department of Agriculture flood-control surveys in the Northeast.

To summarize: moisture-storage properties of forest humus depend on the quantity accumulated and its water-holding capacity. Both vary, though there is relatively more variation in the former than in the latter. Data giving maximum accumulations are inconclusive; but as a rough estimate, hardwood stands in New England develop humus layers 2.5 to 7.5 inches deep while humus under softwoods may average slightly deeper.

Among natural environmental factors that affect humus type and depth are climate, soil, topography, stand composition, and age. Man's activities such as cutting, fire, and grazing may drastically alter the normal humus-formation processes.

SUGGESTED RESEARCH

The obvious and major gap in our knowledge of the water-storage relations of forest humus pertains to humus depth and type under various types and conditions of forest cover. The data cited in this paper permit only an estimate of the range of normal accumulation. Considering that for at least a half-century forest humus has generally been believed to influence the disposition of precipitation and streamflow, it is somewhat surprising that better quantitative data are not available. This paradox may be due in part to the fact that heretofore qualitative recognition of the relationship sufficed, and quantitative understanding was not called for. It may also be due in part to the feeling that humus accumulation is extremely variable, even under undisturbed conditions, and therefore is difficult to study.

Information at hand indicates the research needed to define better the effect of stand and environmental factors on humus development and storage capacities:

1. Determine the water-holding capacities of litter and humus layers of representative forest types.

2. Determine the ranges of humus depths and humus types under representative forest types in undisturbed sapling, pole, and sawtimber stands. Factors of climate, soils, and topography should be stratified or held constant so that their influence on humus development will not confound the effects of forest type and age.

3. Study the influence of climatic, topographic, and soil variations on humus accumulation. A minimum goal of such a study might be to determine if humus formation is modified by such variations in the White Mountain area and, if so, the direction of such modifications.

4. Determine the effect of different degrees of cutting on humus accumulation and the physical properties of humus.

5. Determine the time required to transform a firm mull to a humus type of more favorable moisture relationships.

EVAPORATION

Evaporation of moisture from the forest floor has two facets: the reduction in soil evaporation through the insulating effect of organic layers, and the evaporation of moisture from the forest floor per se during the course of successive wettings and dryings. As far as is known, no research in the Northeast has been conducted on either process.

According to Kittredge, evaporation from a soil covered by a forest floor ranges from 10 to 80 percent of that from bare soil (and evaporation from a bare soil is generally limited to the upper foot). The reduction varies with the type of humus and increases with forest-floor depth up to 2 inches (12). (Depth of mull humus cannot be compared with depths of mor humus or litter when considered in the sense of a mulch.) More recently, Rowe has found that in pine forests in the Sierra Nevadas, a forest floor 1/2 inch deep was as adequate as greater depths for controlling evaporation from underlying soil (27).

Rowe also makes the interesting point that although annual evaporation from a forest floor can reach important amounts, it can be more than compensated for by saving in evaporation from the total soil. The 3-year average of evaporation from lysimeters under a Ponderosa pine forest

floor 2.5 inches deep was 7.91 inches as compared to 13.61 inches from a lysimeter kept bare, a difference of 5.70 inches. In contrast, annual evaporation from a 1-inch deep pine forest floor was 1.46 inches, and for one 3.6 inches deep, 2.60 inches.

From studies in Nebraska of the control of soil evaporation by wheat-straw mulch, Russel has made several pertinent observations (28). He found, for instance, that light applications of straw to a depth of 0.75 inch were almost as effective in reducing evaporation as depths up to 6 inches--which substantiates Rowe's findings (27). About half of the mulch's value was due to its shading effect, and the remainder was due to heat insulation and obstruction of vapor escape. As soon as the surface soil dried, Russel noted, the soil in effect provided its own mulch, reducing the influence of the organic covering.

From an upland hardwood forest floor in Tennessee, the amount of water evaporated after isolated storms was estimated to be 0.05 inch, amounting to about 1 inch annually. This is roughly 4 percent of the annual evapotranspiration of about 26 inches. This loss was considered minor in comparison with the retardation effect of the forest floor on total soil evaporation (2).

Rates of evaporation of moisture from humus appear to vary with latitude. In Mississippi, Broadfoot found that a hardwood floor lost 95 percent of its field capacity in 5 days (3). In the Tennessee study cited above, 12 days were required to reach one-fourth field capacity (2).

Greater humus depth characteristics of the Northeast, compared to more southern latitudes, and associated greater water-storage capacities, would have the dual effect of providing maximum reduction of soil evaporation and greater evaporation from the soil humus per se. Lower temperatures of the Northeast, however, could reduce the drying rate between storms and thus the total amount of moisture loss. Until quantitative data are obtained, these relationships remain speculative.

SUGGESTED RESEARCH

Two general projects are indicated:

1. Evaporation from the forest floor.--Determine amounts of moisture evaporated from different types and amounts of litter.

2. Evaporation from the soil.--Determine the depths of different humus types and litter layers required to keep evaporation from soil at a minimum.

GENERAL SUMMARY

Watershed functions of forest humus involve its effect on infiltration and percolation, water storage, and evaporation. The direction and magnitude of these effects reflect the physical properties of humus; namely, its light weight, porosity, and great water-holding capacity. These properties of humus vary with the humus type. Mor humus is lighter in weight and has greater porosity than mull humus. Within the mull types, firm mull is the heaviest and the least porous.

Most humus types have high infiltration and percolation rates; several studies have shown that infiltration was sharply reduced and surface runoff increased many-fold after humus was removed from test plots.

Considerable variation exists in humus depth and water-holding capacity. Generally, in the Northeast, depth of hardwood humus will range between 2 and 5 inches with water-storage (detention) capacities of about 0.5 to 2.0 inches. Conifer humus, somewhat deeper, will vary between 3 and 6 inches with storage of about 1 to 2.5 inches. Average maximum humus depths of both conifers and hardwoods in northern New England are in the neighborhood of 7 to 8 inches. In southern New England they are about one-half as much.

Humus depth is affected by a large number of environmental and induced factors, many of which are expressed through site quality. In the Northeast, conifer humus accumulates at the rate of about 2/3 inch every 10 years. Comparable rates for hardwoods are about 3/4 inch on medium-textured soil and about 1/4 inch for coarser soils.

Humus type also is affected by environmental and induced factors. Certain soil and stand conditions tend to favor mor over mull humus, but the relationships are not clearly understood.

Humus reduces evaporation from underlying soil, the reduction tending to more than compensate for the moisture evaporated from the humus layers.

Few studies have been made for the express purpose of determining quantitatively the hydrologic role of forest

humus in watershed management. Major gaps in our knowledge are:

1. The water-holding capacities of litter and underlying humus layers of representative forest types.

2. The relationship of humus depth and type to forest type, age, and treatment as influenced by the environmental factors of climate, soil, and topography.

3. The inter-relationship of forest humus, frost type and depth, and winter infiltration.

4. The influence of humus type and depth on summer infiltration.

5. The influence of humus on aggregation and percolation.

6. Evaporation of moisture from humus and underlying soil.

APPENDIX

KEY FOR CLASSIFICATION OF FOREST HUMUS TYPES (7)

The following humus classification system was developed by the Committee on Forest Humus Classification, Forest Soils Subdivision, Soil Science Society of America (7). Thus it replaces the earlier humus classification of Heiberg and Chandler (6) on which it was built.

A. No H-layer; A_1-horizon an intimate mixture or organic matter and mineral soil, with gradual transition between the A_1 and the horizon beneath. F layer may or may not be present.....MULL (2,3,4)[7]

1. A_1 essentially single-grain or massive, without aggregates. Organic matter appears to be more or less uniformly distributed throughout.

   (a) Massive and firm with generally less than 5 percent organic matter by weight.....Firm Mull

   (b) Loose, with low to medium organic-matter content (usually less than 10 percent) and consisting of a mixture of mineral soil and organic matter as single grains. Typically on sandy soils.....Sand Mull

2. A_1-horizon granular or crumb structure. Concentration of organic mater and granular structure most pronounced in the upper A_1 and decrease gradually with depth.

   (a) Coarse granular or crumb structure; many granules 1/8 inch (2/3 mm) or larger. Usually 5-20 percent organic matter.....Coarse Mull

   (b) Medium granular or crumb structure; the larger granules about 1/16 inch (2 mm) or slightly smaller. Wide range of organic-matter content, usually 5-30 percent.....Medium Mull

   (c) Fine granular structure; frequently has the appearance of fine black sawdust; organic-mat-

[7] Numbers refer to Explanatory Notes at end of key.

ter high, usually over 30 percent..Fine Mull (6)

3. Complex mull types. Distinct structural differences between layers within the zone of organic matter incorporation.

   (a) Fine mull underlain by coarse or medium mull... .....Twin Mull

B. H and F layers present with an underlying A_1 horizon essentially similar to that of a true mull. Gradual transition from H to A_1 and mineral soil beneath. (This type possesses some of the characteristics of both mulls and mors.).....DUFF MULL (4,5)

   1. Combined F and H layers more than 1 inch thick. .....Thick Duff Mull

   2. Combined F and H layers less than 1 inch thick. .....Thin Duff Mull

C. H layer present (except in 3 below). Practically no mixing of organic matter with mineral soil. Abrupt transition from surface organic matter to underlying horizon.....MOR (4)

   1. The H layer more than 1/2 inch thick.....THICK MOR

      (a) The H layer has a fine granular structure. .....Granular Mor

      (b) H layer structureless, feels greasy when wet, but hard and brittle when dry.....Greasy Mor

      (c) H layer feels and looks felty, due to presence of fungal hyphae and/or plant residues but not living roots.....Felty Mor

   2. H layer less than 1/2 inch thick.....THIN MOR

   3. H layer lacking or present only as a thin film in depressions.....IMPERFECT MOR

Explanatory Notes

(1) This key does not apply on areas where the upper A horizon shows evidence of prolonged water saturation, such as mottling, peat layers, or bog conditions.

(2) After disturbance of the forest cover, a mull may develop on an old podsol. As a result, a remnant of a

leached layer may be present in the profile even though the layer above it resembles the A_1 of a mull. In such a case, the humus type is typed as a mull on the basis of the characteristics of this A_1 horizon.

(3) A complete description of a mull or duff-mull type should furnish the depth of organic-matter incorporation in inches. For grouping data and reconnaissance use, the following depth classes are suggested: very shallow, less than 1 inch; shallow, 1 to 2 inches; deep, 2 to 4 inches; and very deep, more than 4 inches. For example, a sand mull with organic matter incorporated to a depth of $1\frac{1}{2}$ inches would be a "Shallow Sand Mull."

(4) When it is apparent that plowing or grazing have modified or eliminated the natural humus type, this should be indicated by adding the letter "P" or "G" to the name of the humus type. For example, Firm Mull-P or Firm Mull-G; or Firm Mull-PG if both plowing and grazing have caused present conditions. On previously cultivated land, there is frequently an old plow layer that is comparatively homogeneous throughout but may usually be recognized by the sharp line of demarcation at the base of the plow layer. The humus type should be based on the characteristics of the H and/or A_1 horizon, and not on the properties of the entire plowed horizon. Grazing causes compaction of the organic horizons and may reduce a mull with granular structure to firm mull, or may mix the H-layer of a mor with mineral soil, creating a mull-like condition. Again, humus type should be based on the H and/or A_1 horizon, adding the letter "G" to indicate that grazing was responsible.

(5) As stated in explanatory note No. 3, the depth of organic matter incorporation should be given in the description. The adjectives for the depth classes should be used as prefixes in describing the A_1 portion of the duff-mull. For example, "Thick Duff Mull with shallow A_1" would be used to describe a duff-mull with F and H layers more than 1 inch thick and the A_1 horizon 1 to 2 inches deep.

(6) Because of the high organic-matter content in the A_1 horizon of fine mull it may occasionally be confused with the H layer of granular mor. This is particularly true when the horizon or layer is shallow or thin. In this case, if transition to the mineral soil horizon below is rather abrupt and the organic content so high that it cannot be determined in the field, whether it

is actually fine mull or a granular mor, the layer should be classed as H layer and typed as mor.

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